Enhancing Arden-Syntax-Based Clinical Reasoning with Ontologies

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Abstract. We present an innovative approach to clinical decision support by integrating Arden Syntax with an ontology. By merging these technologies, typically used separately, we address the significant challenges of linguistic variability and data incompleteness in medical diagnostics. Our methodology enhances the accuracy of interpreting complex medical data, demonstrating notable improvements in real-world clinical settings. The results suggest promising directions for future enhancements in clinical decision support systems.

Keywords. Clinical decision support, Arden Syntax, ontology, Momo, ArdenSuite

1. Introduction

In the rapidly evolving field of clinical decision support (CDS), the ability to accurately interpret complex medical data remains a significant challenge. Traditional systems, while robust, tend to struggle with the linguistic variability and incompleteness typical of real-world clinical environments [1]. This paper aims to address this issue by integrating two technologies which are typically used separately in CDS: Arden Syntax [2] and ontologies.

Arden Syntax is a formalism for representing executable medical knowledge established in 1992 and maintained by Health Level 7 International (HL7).

An ontology in its basic definition is a formalized representation of domain-specific knowledge [3]. While most contemporary approaches to utilizing ontologies in CDS often focus on so-called clinical reasoning ontologies [4], we present a completely different approach, the idea for which has been showcased by ID Information und Dokumentation im Gesundheitswesen (ID Berlin) at the 2017 eHealth Summit Austria [5].

Our approach leverages the tried and tested Arden Syntax for clinical reasoning while utilizing an ontology similar to a thesaurus as defined by ISO 25964-1 [6]—in contrast to an ontology based on semantic web technologies—exclusively for semantic reasoning. By uniquely combining these two technologies, we aim to enhance the

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interpretation of complex medical data by harnessing the strengths of both Arden Syntax and ontologies while minimizing their respective weaknesses.

2. Methods

The inception and implementation of our approach can be broken down into “sections”. The impetus was given through Momo (monitoring of microorganisms) [7], a clinical microbiology analytics tool by Medexter Healthcare which has been in active operation at University Hospital Vienna (UHV) since 2013.

2.1. Integrating the ontology

Momo has been in operation at, where it initially relied exclusively on coded entries and results which were each mapped to a human-readable representation in a basic terminology [8].

However, due to user demand as well as the concrete implementation of the laboratory information system at UHV, it became necessary for Momo to include natural language processing of free-text elements [8]. As also described by de Quirós et al. [1], Momo was then confronted with a variety of synonyms, misspellings, and ambiguous acronyms, leading to the necessity to improve the terminology management.

Hence, Momo was updated to utilize a basic ontology service in order to allow for the rich expressiveness of free-text entries while at the same time enabling automated processing [8, 9]. The ontology service was implemented as a stand-alone microservice with a RESTful API to allow for flexible reusability across different applications. Since the initial use-case for the ontology service was merely to allow for the usage of different *terms* (including misspellings) for a single *concept*, implementation focused on the equivalence relationship as well as monohierarchical relationships [6].

2.2. Updating the ontology and integrating Arden Syntax

Due to the increasing need for and acceptance of automation in clinical care discussed in [9], the ontology was updated to fully integrate polyhierarchical relationships. This choice was initially made to simplify the execution of complex analyses, concretely regarding antimicrobial resistance (AMR) surveillance and benchmarking. An acyclic directed graph representing an excerpt of the updated ontology is depicted in Figure 1.

However, it was soon realized that the updates to the ontology could facilitate a way of bottom-up reasoning which might directly benefit the top-down reasoning of knowledge-based CDS systems, such as those built upon HL7’s Arden Syntax. Arden Syntax structures clinical rules into so-called medical knowledge modules (MLMs), each receiving input data—such as laboratory test results—which the clinical rules are applied to so as to produce an output, e.g., a clinical interpretation of the provided findings.

The new structure of the ontology drastically simplifies the necessary logic for an MLM to recognize a specific finding as belonging to multiple, possibly relevant, groups. For example, as depicted in Figure 1, the clinical finding of *Pseudomonas aeruginosa 4MRGN* (multidrug resistant Gram-negative, resistant to four groups of antimicrobials) is a subordinate concept of both *Pseudomonas aeruginosa* (with all its superordinate concepts) as well as *4MRGN*, which was newly added as a top level concept to support AMR surveillance.

To showcase this newly found synergy, a prototype for an alert service with the ability to directly interact with Momo was implemented [10]. The alert service adheres to a microservice architecture, as depicted in Figure 2, and will be further discussed in section 3.2.

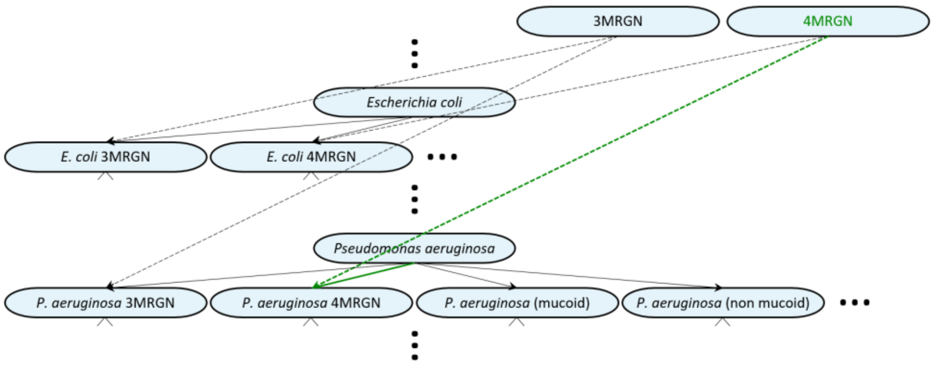

Figure 1. Excerpt of the directed acyclic graph (DAG) representation of the ontology, showing an example of a newly added polyhierarchical relationship. The depicted concept of focus is *Pseudomonas aeruginosa 4MRGN*. The direct parent concepts—broader term (instantial) of the first degree in the language of ISO 25964-1—*Pseudomonas aeruginosa* and *4MRGN* are marked in green. Associated broader terms with higher degrees of superordination are listed in the description on the bottom while they are left out of the DAG for clarity. The subgraph containing vertices regarding *Escherichia Coli* is included to illustrate the overall complexity of the ontology.

3. Results

Even the mere improvements to the ontology service discussed above, without the addition of Arden-Syntax-based reasoning, enabled Momo to be usable for more complex analyses than ever before. For example, a population-level modeling analysis regarding the burden of disease caused by specific antibiotic-resistant bacteria could be successfully conducted and is presented in [11].

3.1. Alert Service

A prototype [10] of an alert service following the microservice architecture was implemented as a proof of concept focusing on antibiotic-resistant bacteria of public health concern, namely

- Methicillin-resistant *Staphylococcus aureus* (MRSA),
- Vancomycin-resistant *Enterococcus faecalis* or *Enterococcus faecium* (VRE),
- multidrug resistant Gram-negative bacteria resistant to either three (3MRGN) or four (4MRGN) groups of antimicrobial drugs, and
- bacteria producing extended spectrum ß-lactamase (ESBL).

The prototype ingests microbiological laboratory test results from a data source like Momo and fetches the preferred term as well as superordinate concepts of each finding from the ontology service. If appropriate, alerts are then produced by an Arden-Syntax-based rules engine—in this case Medexter Healthcare's ArdenSuite Server [12]—and sent to a consumer—e.g., a hospital information system or mail server—via a message broker, as depicted in Figure 2.

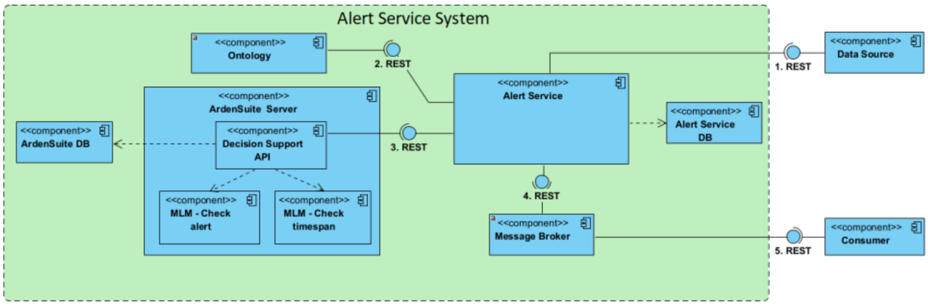

Figure 2. The microservice-based architecture of the prototype for the alert service proposed in [10]. In this setup, Momo acts as the data source.

The prototype was evaluated using 13,639 entries collected at the UHV over the course of a week. Out of these, 13,242 (97.1%) were processed successfully while 397 entries were classified as invalid due to missing information in the received files. The average processing time of each entry was 146 ms and a total of 29 alerts were generated, proving effectiveness and efficiency [10].

A variant of the prototype focusing on potentially pandemic-causing viruses for use in the intensive care unit of the UHV is currently in development.

4. Discussion

A prototype for an alert service utilizing an ontology has been implemented. In contrast to clinical reasoning ontologies, where the entire clinical reasoning is performed within the ontology itself, our approach leverages an Arden-Syntax-based rule engine.

Representing just the semantic relationships in the vast domain of medicine can already lead to significant complexity, as hinted at in the simple example provided in Figure 1. The inclusion of clinical as well as semantic relationships in an ontology greatly increases this complexity. In contrast, the thesaurus-like structure of the stand-alone ontology used in our approach minimizes complexity while maximizing interoperability.

The clear separation of concerns between the ontology for natural language processing and the Arden Syntax engine for clinical inferencing positively affects extensibility and maintainability. In order to change the clinical scope of the alert service, only the relevant MLMs must be adapted appropriately while the same ontology can be reused for multiple purposes. Furthermore, the domain-specific nature of the Arden Syntax as well as its modular structure allow for the representation of highly complex relationships, even including external dependencies, as well as easy adaptation. In contrast to purely Arden-Syntax-based CDS systems, integration of an ontology allows for enhanced processing of input data while minimizing the necessary complexity of each MLM.

The prototype was validated on a set of data acquired in routine operations of UHV, proving the feasibility, efficiency, and theoretical effectiveness. However, utility in clinical practice remains to be tested via a comparative analysis in the context of a clinical study.

5. Conclusion

The successful implementation of a prototype for a novel approach to enhancing CDS systems with ontologies has been presented. The approach enhances the tried and tested Arden Syntax by utilizing an ontology for natural language processing as well as conceptualizing semantic relationships.

The prototype’s functionality was validated successfully in terms of efficiency and effectiveness. Nonetheless, further research is required to confirm benefits to clinical practice. While the inclusion of a virology module to be evaluated in practice at UHV is currently underway, further possibilities for future work include a quantitative comparison of our approach with purely ontology-based clinical reasoning.

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